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Affordances of Mobile Virtual Reality and their Role in Learning and Teaching

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In this paper, we report the technological affordances of a virtual reality smartphone-driven educational app – Google Expeditions. Based on a large exploratory study, we discuss how these empirically-derived affordances support pedagogical approaches of experiential learning, bridging virtual fieldwork with physical field trips, and inquiry-based learning.

Affordances; Google Expeditions; Simulations; Virtual field trips; Virtual Reality; Visualisation

1. INTRODUCTION

Virtual reality generates realistic images, sounds and other sensations to replicate a real environment, or to create a non-realistic setting. A user can access virtual reality (VR) through visual, auditory and haptic sensorimotor channels [11]. The characteristics of VR are 3D images, virtual objects that behave similarly like their real-life counterparts, and features that enable interactivity with the virtual environment. VR has been used as an educational and training platform for simulating object behaviours (e.g. in manufacturing [17]) or visualising difficult concepts [15] (e.g. a solar system), or for treatment in psychology (e.g. phobias [25]).

Virtual reality is being delivered in various ways – ranging from smartphone-driven VR using VR headsets such as Google Cardboard and Samsung Gear VR, to desktop-driven VR with head-mounted displays such as in HTC Vive, Oculus Rift and Sony PlayStation VR. Further, 3D virtual environments can be accessed on desktops and mobile devices that may not require a VR headset as in the case of 3D virtual world Second Life (or in Sansar, a social VR platform to be launched in 2017), or in 3D virtual environments developed in game development platforms such as Unity 3D. For example, UK's Open University's 3D virtual geology field trip, a simulation of the Skiddaw mountains in UK's Lake District, was developed in Unity 3D [1].

Virtual reality can be a single-user experience as in smart-phone driven VR, or users may experience other users (as avatars or otherwise) in 3D virtual environments and in mixed reality environments.

Various smartphone-based VR applications (apps) have emerged that allow users to access and

navigate 360-degree photospheres and 360 videos of real or simulated places for educational purposes. For example, there are 360-photospheres of places such as Galapagos Islands or Great Wall of China, or WaterAid's VR documentary 'Aftershock', which has 360 videos to highlight Nepal's challenges to restore water access after devastating earthquakes in 2015. Further, VR can provide experiences of unrealistic events, such as bringing dinosaurs to life in the 360 videos, a collaboration between Google Arts and Culture and The Natural History Museum (<http://bit.ly/2obn438>).

The move of virtual environments towards mobile devices and VR viewers has helped to democratise and turn VR into a tool that can be used easily with the minimum hardware setup of a smartphone, as compared to other configurations that require head-mounted displays tethered to powerful computers (e.g. Oculus Rift, HCT Vive etc.), or expensive laboratory gear (e.g. 3D projectors etc.).

1.1 Smartphone-driven Virtual Reality in education

The field of education can be a key beneficiary of the smartphone-based VR app trend as it can build on the previous adoption of apps in schools [23]. As we have learned from our interactions with educators, smartphones are already being used in some lessons, and many schools already have 1:1 tablets for their students on which they can run VR apps.

We have encountered two types of mobile VR educational apps:

The first type are self-guided apps that students can run themselves on the smartphones to support self-directed learning. Examples of such apps are Fieldscapes (<https://www.fieldscapesvr.com>) (360-

degree simulations of the Carding Mill valley in the UK which is a popular site for physical fieldwork in geography and environmental sciences) and Carding Mill (360-photospheres of the Carding Mill valley). These apps allow students to navigate through the valley in fly-over or walk modes, and learn about river profiling and the effects of floods on the environment.

The second type are apps targeted for schools which adopt a guide-follower paradigm in which an educator (a person who provides instruction or education; a teacher) controls the viewing of the content on the smartphones of the students. One such initiative for schools is by Nearpod, which allows an educator to show presentations, photos, panoramas, and documents through their tablet onto mobile phones held by the students in a lesson. Students viewing the content of panoramas or 360-degree photospheres via VR viewers are able to get a 3D view/effect. A similar initiative to Nearpod is the Google Expeditions app, which has been the focus of our research.

1.2 Google Expeditions

Google Expeditions (GEs) are guided field trips to places that students experience on a smartphone through a VR viewer called Google Cardboard. The GE app (available for Android and iOS platforms) has more than 500 expeditions. An expedition comprises of 360-degree photospheres of a location (e.g. Rio de Janeiro). GEs enable visualisation of locations which may not be feasible or easy to visit in real life (e.g. Great Barrier Reef or Tolbachik volcano). Further, GEs have simulations to envision concepts and systems such as the human heart, the respiratory system, or the process of pollination.

Using a tablet and via the GEs app, the educator guides the students to look at the scenes of an expedition. The students use the app in the 'follower' mode and experience the GE/VR through the smartphone embedded within a VR viewer. Figure 1 (a) shows a tablet and a cardboard viewer with the phone slotted in; in (b) the tablet is in 'guide' (or educator) mode and the phone is in 'follower' (or student) mode. On the tablet, the educator selects a point of interest (the circle). A smiley face on the tablet shows where the student is currently looking.

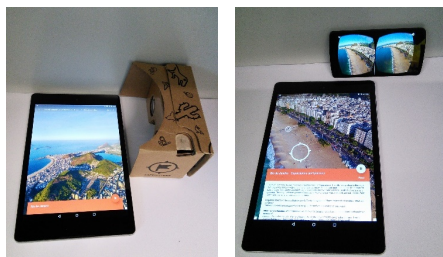


Figure 1: (a) Tablet and a cardboard viewer with the phone slotted in; (b) The tablet is in 'guide (educator) mode and the phone is in 'follower' (or student) mode.

2. THE RESEARCH PROJECT

The research being reported in this paper is based on the results of an year-long school-based project into the potential use of VR via GEs in primary and secondary school science and geography. The outcomes of this research will guide educators to make informed decisions about integrating VR in these and other disciplines.

Three research questions have been investigated:

- How effective are simulations in VR-based GEs in representing concepts and processes?
- How can VR-based virtual field trips such as in GEs support physical fieldwork? and
- How can GEs support inquiry-based learning?

In the next section, we present our research methodology, and following that, we describe the technological affordances of GEs, as derived from our empirical research that support learning and teaching. These technological affordances refer to the characteristics of smartphone-driven VR (or GEs, in our case) that influence their usage in learning and teaching. For each affordance, we outline the perceptions of the educators and students, and exemplify the perceptions with quotes from our data. Guided by the three research questions listed above, we then discuss the pedagogical approaches that are supported by the affordances of GEs. We conclude the paper with a discussion on the role of smart-phone driven VR in learning and teaching – from schools to further and higher education, and reflect on the complexity and fidelity of VR technologies and user-perceptions.

3. METHODOLOGY

For our empirical investigations, we have adopted an exploratory approach [7] - through which it has been possible to examine the domain of smartphone-driven VR in education that has had limited previous research. Smartphone-driven VR is an emerging technology that has yet to be widely adopted in education and the exploratory approach has offered a strong grounding for initial research into its potential for adoption.

The data-collection involved:

- in-school activities with (n=521) students (study Year 4-11) and educators where we conducted participatory observations of lessons using GEs (geography n=10; science n=12);
- one physical field trip that used GEs during the field trip and involved 68 students; and
- written activities with students (in class and on the field trip);
- post-lesson semi-structured interviews with educators (geography n=9; science n=11);

- in five workshops (Figure 2), we have collected data from educators (n=31) and fieldworkers (n=19); and 6 curriculum experts have participated in semi-structured interviews.



Figure 2: Workshop with fieldworkers at UK's Field Studies Council centre at Preston Montford, Shrewsbury.

For students, we developed written activity-sheets specifically addressing the third research question on inquiry-based learning. Following the interaction with GEs during a lesson, the educator asked students to carry out two activities:

- to write down the questions they had on the topic of the lesson; here our aim was to investigate whether GEs provided them with the stimulus to construct higher-order inquiry questions; and
- if and how VR influenced their understanding during the lesson.

At the end of each lesson, educators looked at a subset of student-scripts and analysed the quality of the questions based on a codebook for inquiry-based learning that we have developed based on [4] and [21]. Questions were classified as 'high-order', 'medium-order' or 'low-order questions' (Figure 3).

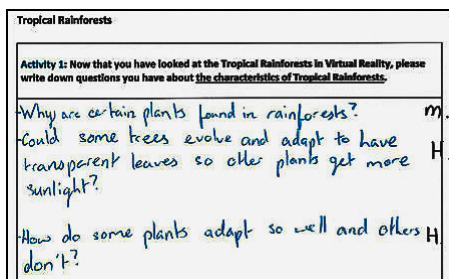


Figure 3: Sample of filled student activity-sheet. The markings on the margin are codes written by the educator (m: medium-order question; H: high-order question) against each of the questions.

For all other participants (educators, curriculum experts and fieldworkers), we developed semi-structured interview protocols. In order to cover all our research aims, interview guidelines were complemented with written activity sheets in which participants could provide more detailed explanations and perceptions. The ethical considerations and the research design was approved by the University's Human Research Ethics Committee. All data collection events were

audio-recorded and the data was transcribed verbatim. The transcripts were analysed inductively in NVivo through thematic and axial coding [6].

4. AFFORDANCES OF GOOGLE EXPEDITIONS

The term affordance refers to the perceived and actual properties of an object that determine how the object could possibly be used; a chair affords ('is for') support and, therefore, affords sitting ([16], p. 9). The design of an object has to be 'perceived' to be of use to the potential user – hence, the emphasis on 'perceived affordance' by Norman in [8].

In our research reported in this paper, we have followed Norman's interpretation of affordance as it is the participants' (educators and students) perceptions of the affordances of GEs of how GEs support their learning and teaching, and influence their experiences with virtual reality.

In the case of learning technologies, the affordances emerge as educators use the technology and reflect on its usage to uncover new affordances to use the technology in their teaching [3]. For a student, an affordance emerges in their interaction with the learning environment – what the student is able to do with the learning environment [22] (e.g. a blog for reflection, or a wiki for collaboration, or a photo-sharing site for a portfolio). There have been earlier attempts by HCI and educational researchers to classify affordances. Bower and colleagues in [2] and [3] presented a framework of technological affordances in which they matched the requirements of learning tasks with the affordances offered by technologies. Dalgarno and Lee in [8] reviewed the literature, reflected on their experiences with 3D virtual worlds, and then proposed the educational affordances of 3D virtual worlds. In this paper and in our research, the relationship between technological affordances of VR and GEs and how the affordances contribute towards learning and teaching have been empirically-derived through a systematic user-centred methodology outlined earlier.

The technological affordances of VR-based GEs emerge from the user interface design characteristics of GEs. During thematic analysis of the data, we found that participants referred to affordances of GEs to describe their experiences and perceptions. We have identified 10 affordances of GEs in our data. For each of the affordances, we will discuss the perceptions of our participants: how their experiences of learning and teaching with VR were shaped by GE's affordances. For each of the affordance and the associated perceptions, we have included quotes to exemplify the experiences.

360-degree visual authenticity

360-degree photospheres in GEs are of physical places that capture every possible viewing direction, thereby, providing a wide field of view. The

perceptions of participants towards this affordance were: accurate physical representation of the space; spatial relationships, sense of spatial presence, and experienced immersion.

The perception of accurate physical representation is influenced by the high-fidelity 360-degree photo. First, the photosphere allows a 360-degree view of the area. Second, the sizes of objects, their proportions and how these influence the observed environment are accurately perceived. An educator referred to this affordance in the GE of rainforests: '[...] the buttress root one [scene] where they could look down and look up and there's such a difference between the dark of the floor and then up at the canopy. I think they really got that difference. I think for the first time they could appreciate the layers, because you talk about it being forty meters high, but it's not until you have to zoom in up to the top that you realise just how tall that is.' (Geography educator, GE: Borneo Rainforest).

The perception of spatial relationships refers to the ability to observe relationships between the elements of the photosphere such as spatial influence – the effects of a place on a surrounding area [13]. 360-degree authenticity that offer a bird's eye view over large areas can support the teaching of geographical issues such as tourism and the location of rich and poor areas relative to places of tourist attractions.

For example, in the expedition on Rio de Janeiro, the scenes show the city from above and one can notice the tourist landmarks, such as Christ the Redeemer and Copacabana Beach: 'for example, the areas of Rio de Janeiro which are directly affected by tourism [...] attempting to explain these links would deepen students' thinking; for example, why are the slums located some distance from tourist hotspots?' (Geography curriculum expert, GE: Rio de Janeiro and Sao Paulo).

The immersive feeling arises as a student uses the Cardboard viewer to visualise the 360-degree photosphere without any outside distractions from peripheral vision: 'because of that immersion you're almost like covering your eyes, you're blocking out [...] everyone else or everything else' (Computing educator, GE: The International Space Station).

Sense of spatial presence refers to students experience of as if having visited the place: 'you can properly understand the scenes and it seems like you are there' (Year 9 student, Geography, GE: Borneo Rainforest: Plant Adaptations).

360-degree navigation

The students are able to move their head left to right, but also up and down to see the scene all around them. This enables them to orient themselves and to grasp the characteristics of the place they are visiting: 'I could choose where I wanted to look and used this

to deepen my understanding' (Year 10 student, Geography, GE: Rio de Janeiro and Sao Paulo).

The perceptions of participants towards this affordance are: spatial understanding [12]; sense of scale [20] – understanding the proportions of the elements in a scene and how they compare against one another; sense of space – being able to observe and understand the characteristics of a physical location; spatial relationships: 'I think they also got the difference between the edge of the forest where the mangroves were and the middle of the forest.' (Geography educator, GE: Borneo Rain Forests: Plant Adaptations); and causal relationships between different elements of a scene: 'You can actually see if it's dark or light in the rainforest because you can look up but in a photo, you can't look up. I think it was also good as you can look around and see what it looks like everywhere.' (Year 9 student, GE: Borneo Rainforest: Plant Adaptations).

3D view

The lenses of the VR viewer focus and reshape the images in a GE for each eye and create a stereoscopic 3D image. The 3D view affordance is particularly relevant for visualising realistic representations of simulations and for understanding perspectives. In geography, it can support sketching: 'At the moment you tend to show them a photo, but copying from a photo is very, very different than copying from 3D. That would help'. (Geography curriculum expert).

In Science, GEs can support realistic simulations of physical objects: 'so, if you take the alveoli which is the spheres, you can see the capillaries wrapped around. It's very difficult to visualise and how they're arranged [...] when it's on just a flat piece of paper' (Science educator, GE: Respiratory System).

The perceptions of participants were: sense of space; sense of presence; and sense of immersion. 'I could actually feel like I was at the volcano and I could see all around me. It's a lot better than a textbook with just pictures' (Year 8 student, GE: Volcanoes Around the World).

Emphasis

This affordance is specific to the educator or guide-driven mode of GEs on the tablet. The educator can highlight aspects of a scene in an expedition by selecting pre-defined viewpoints or by creating new ones through tapping on the tablet's screen. The students 'follow', or look at the viewpoint while being guided by an arrow on the smartphone VR scene. The educators remarked on the capacity to highlight aspects of scenes (perception of highlight-ability) and its utility: 'I think if you leave them to their own devices, it becomes too free. They haven't really got a structure to hang it on and they could look at anything. What exactly are they learning?' (Geography curriculum expert).

Students perceive this affordance as the capability to be directed towards particular components (focus-ability): 'It was helpful [that] they gave you an arrow to show what you are looking for' (Field trip student, GE: Environmental Change in Borneo).

First-person perspective

The authenticity of the physical spaces in the GEs facilitates the students taking up role(s) of professionals who belong to that context (e.g. astronauts on the International Space Station (ISS), or divers in Great Barrier Reef). The perceptions towards this affordance were sense of presence and taking the role(s) of persons inhabiting the environment. Whereas sense of presence refers to the perception of being at the location shown in the photospheres, taking up roles of professionals implies a further step, towards role-playing and decision making: 'because you are there, you are that person, [...] "Okay, what do I need to look at first? What am I doing?" because you are the astronaut, you are in that situation.' (Computing educator, GE: International Space Station)

In-situ contextual information

On the educator's tablet guiding the VR on student's phones, the scenes in a GE have textual explanations, viewpoints, and suggestions for questions. This in-situ content can be used by educators to plan lessons, develop learning activities, or assess students' learning. In our observations, we have noted that educators use the content to introduce the GE, relate it to the learning outcomes, and to prompt students to viewpoints.

Simulations

The GE app has simulations, such as the human respiratory system, nervous system, the solar system, earth timeline, and earthquake faults. These simulations are virtual representations of otherwise invisible concepts, processes and events. The perceptions of participants in our empirical research were: realism; image detail; and ability to see the connections between elements of a simulation. Realism refers to the visual and behavioural consistency with which the elements of the simulation are illustrated in the GEs; objects look and behave as their real counterparts ([8], [10]): 'the animation was very realistic; therefore, I could take more knowledge away from the lesson [...] these images can [...] help me explain about the respiratory system in a much larger amount of detail' (Year 11 student, GE: Respiratory system). The realism links up with the detail in images in the simulations: 'this was helpful because usually the respiratory system is simply presented as a diagram, but being able to see it so close helped me to feel connected to it'. (Year 11 student, GE: Respiratory System).

The ability to see the connections between the elements of a simulation refers to the perception of

having a contextualised view of the 'whole'. The abstract concepts, systems, and processes are shown within a broader picture: 'Actually seeing where the [alveoli] and why it is and the capillary network around it, being able to picture it, I think helps link those things together.' (Biology educator, GE: Human Anatomy: Respiratory System).

Single-user handling

Each student in the 'follower' mode experiences the GEs through the VR viewer which they hold over their eyes. This creates a single-user experience, unlike in the multi-user experience in avatar-based 3D virtual environment (e.g. Second Life) where one or more users or avatars share the environment. The perceptions of participants towards this affordance were: individual viewing experience and field of view; flexibility for self-guided exploration; potential to follow one's interest and curiosity; not being conscious of others; sense of control; and sense of immersion.

Through an individual viewing experience and field of view, students are able to explore the locations from their own point of view, as compared to watching a movie, where the angle of direction and angle of viewing are guided by the cameraman: 'I think I have understood more as looking around made it easier to experience Rio from my point of view' (Year 10 student, Geography, GE: Rio de Janeiro and Sao Paulo).

This facility of self-exploration enables students to choose what they look at and how much time they spend looking (following their interest and curiosity), hence giving them a sense of control and empowerment over their own exploration: 'Virtual reality gave me a first-person journey through the respiratory system where I could see detailed structures, and study which component I wish'. (Year 11 student, Anatomy, GE: Respiratory System).

Another perception facilitated by the single-user affordance is not being conscious of the events happening around the users. For instance, in the classroom, students might get distracted by peers. By putting the Cardboard viewer on, they can become oblivious of others and focus on their own exploration: 'Suddenly they could just forget about everyone else and just do their thing and... without worrying that other people could see what they're looking at, see what they're doing, ... there's a lot of personalisation that I think is really important for learners.' (Computing educator, GE: ISS).

Synthesis

In a lesson, an educator can use more than one GE, or use GEs alongside other resources such as videos, or sounds. The perceptions related to this affordance were integrate-ability (use more than one expedition) and combine-ability (combine GE with other resources). Through integrate-ability, educators can switch between various expeditions

and show different perspectives: 'This is city life in London. Right, OK, you think this is hectic [...] here's a snapshot of India or here's a snapshot of China'. (Science educator).

Through combine-ability, educators can create a multi-media and multi-modal experience. In two science lessons, educators showed a video on the Chernobyl accident before showing the GE of Nuclear Disaster Aftermath: The Fall Out; two geography educators played rainforest sounds when showing the GE of Borneo Rainforest: Plant Adaptations: 'I thought I could introduce some sounds, because I'm conscious that some of our students [...] won't know what rainforest is like and they won't understand that there might be birds, there might be other noise, there might be the rain.' (Geography educator, GE: Borneo Rainforest: Plant Adaptations).

Visualisation

Visualisations in GEs enable students and educators to access and experience places that may be hard or impossible to visit in real life. Visualisations help to 'visit' or experience places as they were before – e.g. the area around the London Olympic Park before the 2012 Olympics. Students can learn how the area has changed since the Olympics when they visit the area as a part of a physical field trip. The associated perceptions for visualisation were: authenticity; level of image detail; sense of scale; sense of place; and sense of space. Through the perception of authenticity, students no longer have to imagine a place: 'The virtual reality helped me because I could see for myself what was happening without having to imagine it.' (Year 10 student, Geography, GE: Rio de Janeiro and Sao Paulo).

Through the various points of view and close-up imagery, GEs allow users to observe details in the scenes that would otherwise be difficult to see, such as the leaf structure of the giant palm in the rainforest: 'Virtual reality helps you to understand characteristics of the tropical rainforest by seeing things up close which you wouldn't be able to see in real life. It's also a good experience as you can almost touch the rainforest' (Year 9 student, Geography, GE: Borneo Rainforest: Plant Adaptations).

The visualisation gives students a sense of place [20]. They were able to visualise areas that contain both physical features and human settlements (e.g. Bromo Tengger Semeru National Park in the GE: Volcanoes Around the World) and explore the meaning of place for the inhabitants at the bottom of the volcano: 'I think it really helped imagine and understand the effect on the people and on the surroundings' (Year 8 student, GE: Volcanoes Around the World).

Another student said: 'Virtual reality helped me to understand the effects [of radiation]. I was able to fully see some of the sites which the radiation

affected in close range and in detail.' (Year 10 student, GE: Nuclear Disaster Aftermath: The Fall Out).

5. BRIDGING TECHNOLOGICAL AFFORDANCES WITH PEDAGOGY

In our empirical work, we have observed that the educators use the technological affordances of GEs to plan and design activities around a variety of pedagogical approaches. Corresponding to the research questions outlined earlier, in this section, we discuss how the affordances of GEs support the pedagogical approaches of experiential learning, virtual fieldwork, and inquiry-based learning.

5.1 Learning with simulations

There are several simulations in the GEs app – such as the human auditory system, the eruption of a volcano, and the processes of photosynthesis and pollination. These simulations model real-world objects, concepts and phenomena. Simulations of otherwise invisible components such as the human digestive system or the solar system enhance the learning process by simplifying the underlying model so that it comes within the reach of student's understanding [24].

The virtual reality in GEs allows the students to view the simulation but they can't manipulate the interface such as click on an object to open a document, or click on an object to move it. This lack of manipulation or interactivity is unlike other VR environments (e.g. the 3D virtual world Second Life or in Unity 3D-based 3D environments) where a user can interact directly with the interface and observe the consequences of their actions.

The simulations in GEs facilitate the learning of conceptual knowledge rather than procedural training or knowledge. The high-fidelity and realistic simulations and the GE affordances of 360-degree navigation and 3D view provide an opportunity to learn the relationships between the components of a simulation. 'Virtual reality allows me to more easily understand the respiratory system as I have a way to see what exactly is happening during each stage and also how the body has protection at each stage to stop pathogens entering the blood stream.' (Year 11 student, Anatomy, GE: Respiratory System).

In an Anatomy class that we observed (Figure 4), the students had previously had lessons on the respiratory system and, therefore, the simulation helped clarify the connectivity of the various parts (e.g. lungs, alveoli, bronchioles) and their relationships.

Our experience during this project and previous research ([in [25]) has shown that it is critical to 'time' the showing of the simulation – the simulation is only

pedagogically effective when the students already have some basic understanding of the concept or the process in the simulation.



Figure 4: An educator showing the simulation in a biology lesson to Year 11 (GE: Human Anatomy - Respiratory System).

5.2 Learning with visualisations

There are two kinds of virtual field trips in GEs: a) places that may be difficult to experience in real-life such as underwater excursions of the Great Barrier Reef to view the coral bleaching and effects of climate change; and b) places that you may be able to visit in real-life but it may not always be feasible to do so due to resource, distance and mobility constraints such as visiting London Olympic Park, or visiting tropical rainforests in Borneo, or pyramids in Egypt. The affordances of 360-degree visual authenticity, 360-degree navigation and 3D view create an 'authentic learning space in VFTs which facilitate the delivery of conceptual knowledge and the 'learning by doing' or experiential knowledge depending upon the activities that educators can design around the expeditions. For example, looking at the process of coral bleaching can help in understanding the effects of climate change, or looking at Pyramids or Taj Mahal to understand the different types of rocks. Educators can use VFTs: to train students for physical field trips; in the development and practice of fieldwork skills; during physical field trips and after physical field trips.

According to Kolb [13], the key elements of learning through experience are: a) concrete experience (doing); b) reflective observation (observing); c) abstract concept formation (thinking); and d) active experimentation (applying the learning to a new situation). Well-designed physical field trips are a classic example of experiential learning as embodied in Kolb's model. The VR-based 'authentic' VFTs forge a synergistic relationship with physical field trips through technology-facilitated experiential learning. VFTs support the physical field trips by providing a complementary experience that extends from pre-physical field trip stage, during the physical field trip, and after the physical field trip.

VFTs contribute towards *pre-physical field trip* experience in the following ways: preparing for data collection ahead of the field trip (e.g. sampling strategies); making predictions, plan inquiry and

formulate hypotheses; familiarisation with the intended physical field trip; risk assessment; and understanding on what is involved in a field trip even if the planned location for the physical field trip is different from the VFT. 'You can go out in the field and talk about risk assessment but you need to have done that beforehand. The students need to be good at looking at what the risks might be. Showing it to them beforehand and going, "Okay, what do you think the risks are going to be?" would be really useful.' (Geography curriculum expert). Another educator said: 'You could be saying "right, this is what we'll be seeing, let's try and work out a little bit about this environment before we go on to do our own environment.'" (Geography educator, field trip).

In our project, a Geography educator used the GE of Environmental Change in Borneo *during a physical field trip* to a nature reserve to sensitise her students about the impact of change (e.g. construction, tourism) to natural environments like in Borneo (Figure 5). She then asked her students to reflect on how their local nature reserve will change because of the proposed development related to a High-Speed train route that will run close to the reserve.



Figure 5: An educator using GEs during a field trip to a local reserve (GE: Environmental Change in Borneo).

Educators have discussed other benefits of using VR-based GEs *during physical field trips* such as being able to view the details that are not visible to the eye (e.g. geology and rock formations); to be able to see the scenery from a different perspective or vantage point (e.g. what's on the other side of the mountain, what's in the valley, what's beyond the forest); or to make comparisons to other places; or to provide evidence of temporal change (geological times, historical times, seasons, times of the day): 'Also, perhaps the opportunity to observe what that location is like in a number of different conditions, whether that's to do with seasons or any sort of temporal change, really.' (Fieldworker, workshop).

In the *post-physical field trip* stage, VFTs can help in strengthening the inquiry; de-briefing on the field trip; and for synthesising the information and sharing it with everyone after the field trip including those who were not able to participate in the physical field trip: 'I think that that post-field trip thing gets you to asking the questions that perhaps you didn't pose at the start because you weren't really sure what you

were going to see. But I think, yeah, the quality of questioning will improve and that's why GE will kind of sort of remind you or get you to think about things slightly different.' (Geography educator, field trip)

In fact, combining physical and virtual interactions through physical fieldwork and VFT, respectively, may reinforce the learning objectives (and intended outcomes). For example, in pre-physical fieldwork situations, VFTs facilitate practising and allowing for mistakes to be made in a secure environment. The experts we've interviewed mentioned some critical fieldwork skills such as orientation, observation, sketching, getting acquainted with maps, and note-taking that can be practised by students by viewing locations in VR within the GEs, and in conjunction with the physical items they will use in the field (e.g. pens, pencil and field notebooks). In post-physical fieldwork situations, VFTs can help reinforce the learning, facilitate and enable completion of any incomplete tasks of the physical fieldwork, and allow for additional observations.

We have adapted Kolb's model [13] of experiential learning to propose a model of experiential learning in fieldwork that combines the experiences of conducting field work in VR-based VFT with physical fieldwork. It has the following six steps: a) experience a VFT individually and collaboratively; b) practice, explorations and observations in a physical field trips; c) use VFTs during a physical trip to understand areas and perspectives that support learning in the field; d) reflection, practice, further analysis of data and interpretation in VFTs after a physical field trip; e) reinforcement of learning and knowledge construction from both virtual and physical experiences through educator-driven debriefing, feedback and group discussions; and f) applying the learning to new situations and contexts within VFTs, or in the real world.

5.3 Inquiry-based learning

Inquiry-based learning (IBL) involves students collecting and interpreting data, and synthesising the information and evidence to address real-world problems in subjects such as history, science and geography [18]. Inquiry learning enables the development of skills for scientific investigations such as problem-solving and critical thinking [18]. Questions are at the core of any inquiry – questions that the students are curious about and which are situated within the learning outcomes of the lesson. To derive questions, students revisit materials and reshape their thoughts, thereby deepening their understanding [5]. Despite the benefits associated with questioning, researchers consistently report that students ask very few questions in schools [10], and most are clarifications, rather than efforts to gain new knowledge.

Research which was originally conducted in the History but has since been applied in Geography,

Science and related disciplines that have enquiry integral to their curriculum, has shown that there is a need for an initial stimulus material (ISM) or a 'hook' to raise curiosity and to give students a range of areas to think about for their inquiry questions [19]. ISM could be a photo, a painting, video, a presentation, a map, or a role-play activity, and an educator encourages them to work in pairs or groups – so that they could learn to interrogate the ISM and then generate their own questions for inquiry [4].

An ISM helps to cultivate conceptual understanding through concrete examples that connect with the students known and familiar experience. The affordances of visualisation, 360-degree visual authenticity and 360-degree navigation of GEs facilitate understanding the context – where educators relate subject matter content to real-world situations and give students probes to think about the context. For example, a Geography educator showed scenes of the Great Barrier Reef GE where coral had a healthy colour, then where their colour had bleached, and lastly where the corals had been invaded by algae. He asked the students to think about the effects of climate change on corals and the effects of coral bleaching on the underwater life. After looking at the coral bleaching, a student of Year 8 enquired in his written-activity: 'can the colour of the corals before it is drained come back?' The educator assessed the student's question to be a higher-order question: 'you would need to explain why, the fact that it was variable on the coral. It links to the idea of resilience'.

In a Geography lesson (Figure 6) that used the GE of 'Borneo Tropical Rain Forests: Plant Adaptations' as ISM, a student enquired: 'how did the mangrove leaves adapt to take in the salt?' The educator later observed in the post-lesson reflection session with us that it was a higher-order question: 'That's really interesting because they are now asking why? They know they do, now they want to know how.'



Figure 6: Students of Year 10 conducting an inquiry activity in pairs with GE as an ISM (GE: Borneo Tropical Rain Forests: Plant Adaptations).

The experiential learning and in-context learning and teaching [24] afforded by GEs stimulate the student-questioning for IBL. In our in-depth post-lesson semi-structured interviews with educators, they reported that the quality of questions (analytical or higher-order questions as compared to lower-

order or factual or temporal questions) for IBL was higher in a VR session compared to usual lessons.

6. DISCUSSION

Our empirical research has shown how the technical affordances of virtual reality are perceived by educators and students. Guided by our research questions and through an analysis of the research data, we have derived the affordances of GEs/VR and shown how different affordances combine in diverse ways to support a variety of pedagogical approaches: experiential learning; virtual fieldwork and virtual field trips; and inquiry-based learning.

Our focus has been on Geography and Science. There may be other ways in which the educators could design activities to utilise affordances of GEs in other disciplines, and implement other pedagogical approaches such as exploratory learning and reflective learning. For example, students could work in pairs and engage in peer-to-peer learning through completing some evidence-gathering activities set around one or more expeditions. The educators may employ the affordances of social software tools such as wikis, and blogs to design collaborative and reflective activities, along with VR apps such as GEs, and with their existing resource-set of videos and photos.

The GE app has a number of 'career expeditions' where the users can follow the lives of specialist professionals such as coder/entrepreneur, pharmacist, and so on. A science educator, although impressed by the existing current career expeditions in GEs, said: 'Yes, but maybe some more sort of normal jobs for people in working class areas. [...] maybe a policeman, a teacher, even things like a hairdresser. [...] normal jobs and how it's relevant to them, as opposed to elite jobs.'

VR-based GEs can support home-schooling – bringing 'outside to inside' to students who are in pupil referral units and who have been excluded or cannot attend mainstream school for various reasons: children with behaviour issues, those who are ill, school phobics, and teenage mothers.

6.1 Higher education adoption of GEs

Although our empirical research has focused on schools, GEs and their affordances can support further and higher education. In disciplines that have a component of fieldwork, educators in further education (FE) and higher education (HE) have noted that students coming in from a school environment have varied skills-set and perceptions of a physical field trip. These educators have discussed the possibility of using smartphone-based virtual reality to bridge the conceptual and contextual knowledge of students to the requirements of physical fieldwork in FE and HE,

and to facilitate the transition from schools [14]. Future research could investigate whether smartphone-based VR apps have similar positive effects on engagement, focus, curiosity, and lesson participation as we have observed with primary and secondary school students.

6.2 Flexible usage of GEs

The GE app can run both in 2D and 3D modes. The 3D view is facilitated by the VR viewer. However, if the viewers are not available in the lesson, it is possible to run the app on a tablet or on a smartphone in a 2D mode. The GE app with its over 500 expeditions is a useful educational resource and the flexibility of it being used in 2D or non-VR mode opens further possibilities for usage and adoption, independently of the availability of VR viewers.

6.3 Perceptions towards virtual reality terminology

In our data analysis, we have noted that students and educators used terminology specific to virtual environments (VEs) to discuss their experiences or feelings of presence or immersion: 'It was as if I was there'. Terms such as 'sense of presence' and 'immersion' are usually associated with 3D VEs that display animations, avatars and virtual characters which have a higher degree of fidelity and interactivity than photospheres. However, in our research, the effects of VR were perceived even in the context of smartphone-driven VR in GEs using photospheres. There is clearly a need for researchers to adapt measurement instruments for presence and immersion that are currently available for 3D VEs, to the less sophisticated technology provided by a smartphone app and a VR viewer.

Another concept that has emerged in our research is 'co-presence' – a feeling of being together with someone in the VE. In shared VEs, such as in Second Life, co-presence is facilitated by avatars that inhabit the same place. In a GE, co-presence is subtly different: students inhabit the same physical space (the classroom); the GE app runs the same scene on all smartphones simultaneously. Students may experience co-presence in terms of viewing the same scene, even though the app does not display any avatars while they navigate the scenes. However, students experience the VR individually (affordance of single-user handling) and may have a different experience depending upon where they looked in the VR environment. In future research, co-presence could be measured for GE users to investigate whether it has an impact on learning.

7. CONCLUSIONS

Our research was designed to answer three research questions. The results show that the

affordances of GEs can be effective in representing concepts, locations and processes, and can support inquiry-based learning in geography and science. By using the virtual environments in GEs educators can also support the learning gained through physical field trips. However, the choice/adoption of VR in education is limited by various factors: the discipline/subject being studied; fit with the sector (school, further education or higher education); match with the curriculum; and resources available including time, budgets and opportunities for continuing professional development of educators.

In both face-to-face or in distance education, the most effective use of VR will be when it is combined with other technologies such as videos, podcasts, wikis, blogs or forums, and mobile apps. The adoption of VR is still in its infancy and its development will progress and mature as educators (and students) perceive and exploit the affordances of this technology for their teaching and learning.

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